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Development of a strong Goss texture during annealing of a heavily rolled Al–0.3% Cu alloy

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Abstract. The evolution of microstructure and texture during isochronal annealing of a heavily cold rolled Al–0.3% Cu alloy has been characterized using electron backscatter diffraction. It is found that the rolling texture of this alloy is dominated by the Brass component and that recrystallization during annealing leads to the formation of a pronounced Goss texture. It is suggested that the development of the strong Goss texture in Al–0.3% Cu is caused by preferred growth of Goss-oriented grains into the Brass-oriented matrix.

1. Introduction
The rolling texture in aluminum alloys typically contains three prominent components, i.e. Copper {112}⟨111⟩, S {123}⟨634⟩ and Brass {110}⟨112⟩ orientations. During annealing this texture is often replaced by a recrystallization texture with a pronounced Cube {001}⟨100⟩ component, although the deformation texture can also be retained in recrystallized samples [1]. Another frequently reported recrystallization texture of commercial aluminum alloys is a combination of P ~{110}⟨111⟩ and $Cube_{ND}$ {001}⟨310⟩ components [2–4]. A less frequently observed component in the annealing texture of Al alloys is the Goss {110}⟨001⟩ orientation. A strong Goss texture was observed after annealing of heavily rolled pure aluminum [5] and Al–1.8% Cu [6,7]. It was suggested that in these materials, Goss-oriented grains nucleated either in shear bands or in transition bands [5–7]. These suggestions were, however, based on a few orientation measurements made using the electron backscatter diffraction (EBSD) technique. Here we report a strong Goss texture observed after annealing of a heavily cold rolled Al–0.3%Cu alloy. To provide more detailed information on nucleation sites and to study the evolution of Goss-oriented grains, high-resolution EBSD analysis of large areas in rolled and annealed samples is conducted in the present work.

2. Experiment
The material used for the present study was Al–0.3%Cu (wt%) with a very coarse (1.5–2 mm) grain size in the as-cast condition. To produce a plate suitable for rolling, the as-cast material was first forged at 200 °C. An ODF obtained using X-ray diffraction data from the forged plate demonstrated a scatter of orientations near the Brass component with $f(g)_{max}$ = 7.2. The plate was then cold rolled by multiple passes to a total thickness reduction of 98%, which corresponds to a true strain of 4. To ensure homogeneous deformation for each rolling pass, the l/d ratio (where l is the contact length between the roller and the sheet, and d is the average thickness of the sheet [8]) was controlled to be ~2.5. After each pass the material was

immediately quenched in water. The cold-rolled material was then annealed at different temperatures for 1 h.

The microstructure and texture of the cold-rolled and annealed samples were characterized by EBSD in a Zeiss Auriga dual beam station. Specimens from the center layer of the longitudinal section containing the rolling direction (RD) and the normal direction (ND) were prepared for the EBSD analysis. Step sizes for EBSD scanning were 50–100 nm for the rolled and recovered conditions, and 0.5–5 μm for partially and fully recrystallized conditions. Low angle boundaries (LABs) and high angle boundaries (HABs) were defined in the EBSD maps as those with either 2–15° or >15° misorientations, respectively. Texture components were defined within 15° from their ideal orientations.

3. Results

Heavy rolling results in a lamellar-type microstructure with an average boundary spacing of 0.2 μm along the ND, where lamellae of similar orientations compose either broad or narrow texture bands (Fig. 1a). Similar to previous observations of the microstructure in heavily rolled aluminum [4], the band thickness is found to depend on the crystallographic orientation. As is seen in Fig. 1a, bands of the dominant Brass texture (~60% of the area sampled) are broader than individual bands of the other rolling texture components and contain predominantly LABs. The narrower S and Copper texture bands contain lamellae delineated by both HABs and LABs (see Fig. 1a). Localized shear banding at ~35° to the RD is also observed in the rolled microstructure. Goss-oriented crystallites are seen both within lamellar structures and in the vicinity of shear bands. Their area fraction in the deformed microstructure was significant, ~5%. In contrast, the area fraction of crystallites having orientations of the Cube texture was extremely small, 0.01%.

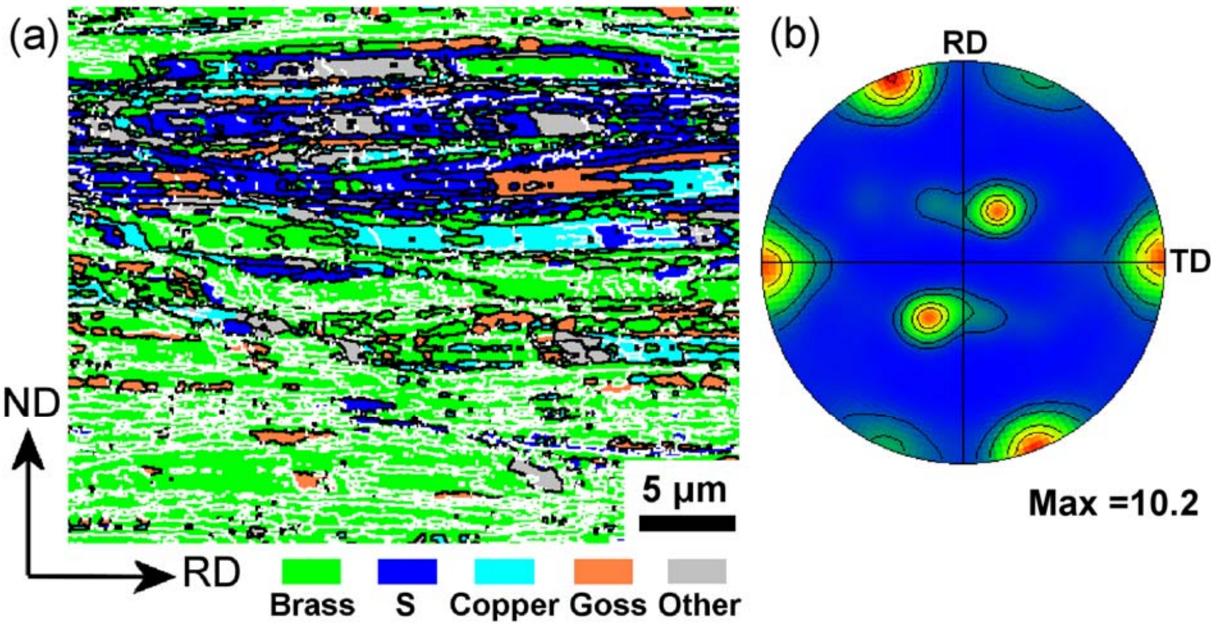

Figure 1. EBSD data for Al–0.3% Cu cold-rolled to a strain of 4: (a) orientation map with LABs and HABs shown by white and black lines, respectively; (b) {111} pole figure for the area sampled in (a).

After annealing at 190 °C for 1 h a number of recrystallized grains are seen in the microstructure (Fig. 2a), including a few Goss grains growing into the Brass-oriented matrix. Annealing at 250 °C for 1 h results in complete recrystallization with a very large fraction of the Goss texture, 54% (Fig. 3). Fig.3a demonstrates that in many cases recrystallized Goss-oriented grains are separated by LABs. Whereas a small number of S- and Copper-oriented grains are also present in the recrystallized microstructure, there are no grains of the Brass components in Fig. 3a.

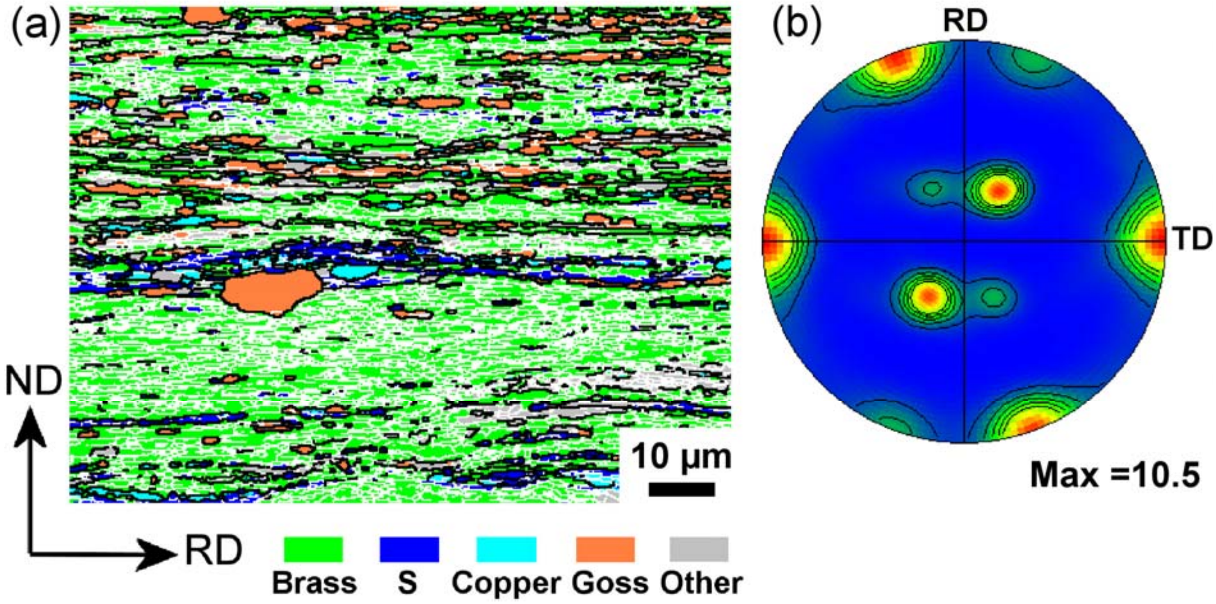

Figure 2. EBSD data for Al–0.3% Cu cold-rolled to a strain of 4 and subsequently annealed at 190 °C for 1 h: (a) orientation map with LABs and HABs shown by white and black lines, respectively; (b) {111} pole figure for the area sampled in (a).

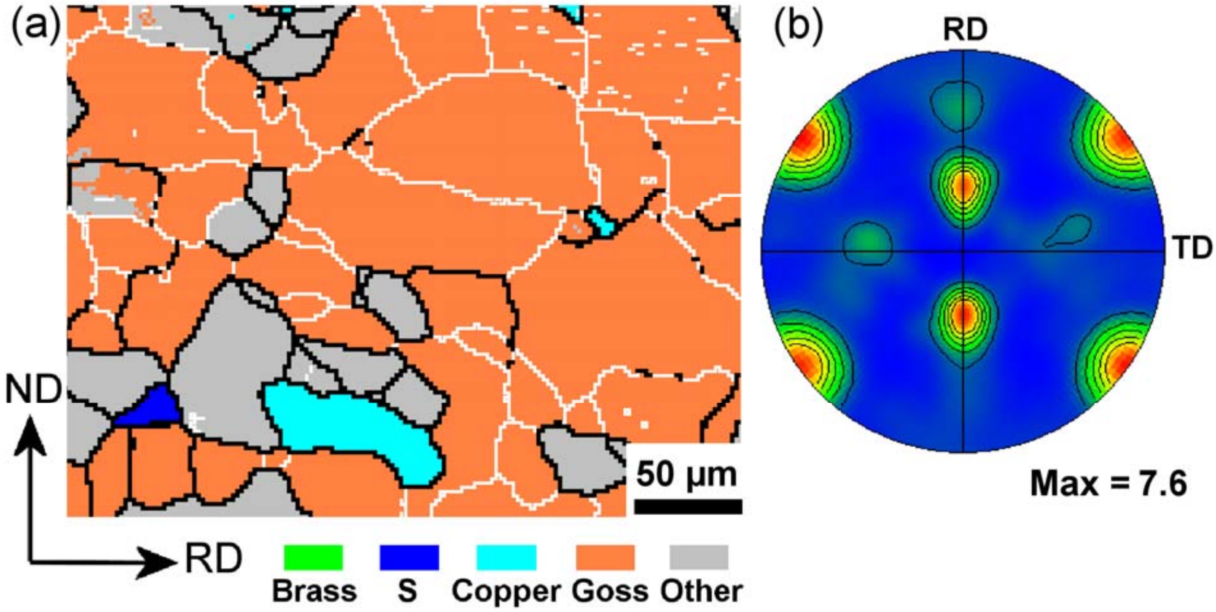

Figure 3. EBSD data for Al–0.3% Cu cold-rolled to a strain of 4 and subsequently annealed at 250 °C for 1 h: (a) orientation map with LABs and HABs shown by white and black lines, respectively; (b) {111} pole figure representing the texture in a large area.

4. Discussion
In contrast to the typical deformation texture developing after high-strain rolling of aluminum, in which the Brass orientation is usually much weaker than the S and Copper components [4], the present Al–0.3% Cu alloy, cold rolled to a strain of 4, contains a very strong Brass component. One possible explanation is that this strong component was inherited from the forged material where orientations near the ideal Brass component dominated the texture (see Section 2). For the given material, the presence of Cu in solid solution could slow down the development of the other rolling texture components during cold deformation. Furthermore, the effect of Cu in solid solution could be similar to the effect of solute Mg in Al–Mg alloys [6,9], i.e. increasing the tendency for shear banding during

heavy rolling. According to Lücke and Engler [6] and Engler et al. [10], intense TD rotation of the Copper orientation takes place within such shear bands, first towards the Goss components and then towards the Brass component. The result of this rotation is a large area fraction of Brass-oriented deformation structures. Subgrains of the Goss component are also present in the deformed microstructure (Fig. 1a). In most cases, these Goss subgrains have at least one common boundary with the Brass-oriented volumes, which is similar to the observations of Hjelen et al. [5]. Such boundaries between the Goss subgrains and the Brass-oriented matrix are typically characterized by large misorientation angles across them (see Fig. 1a).

In early stages of the recrystallization process, nuclei with orientations of the rolling texture components are predominantly observed within coarsened lamellar structures, while nuclei having “random” orientations appear mainly within shear bands. Grains with the Goss orientation are also seen in the partially recrystallized microstructure, both near shear bands and within lamellar structures. These grains and grains with random orientations are expected to have growth advantage due to the presence of highly mobile HABs between such grains and the Brass-dominated deformation matrix (see Fig. 2a). For example, misorientations between the exact Goss orientation and the exact orientations of the Brass, S and Copper components are $35°\langle 110\rangle$, $43°\langle 112\rangle$ and $55°\langle 110\rangle$, respectively. When recrystallization is almost complete, further grain growth takes place in the presence of a very strong Goss texture, which results in many low-mobility LABs formed between recrystallized Goss-oriented grains (Fig. 3a). Thus, at this stage further growth of the Goss-oriented grains is possible mostly at the expense of grains having other orientations, which is expected to further strengthen the Goss texture.

5. Summary

Microstructures and textures have been studied by EBSD in an Al–0.3% Cu alloy cold-rolled to a strain of 4 and subsequently annealed at different temperatures for 1 h. The cold-rolled material is characterized by a rolling texture with a strong Brass component and by a small spacing between lamellar boundaries, ~0.2 µm. Upon annealing recrystallization nuclei are developed both within lamellar structures and near shear bands. Nuclei with the Goss orientation appear to have growth advantage when they grow into Brass-oriented matrix, thus leading to a strong Goss texture in the fully recrystallized condition.

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